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SEP 80 A V OPPENHEIM, J S LIM

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Experimental results supporting the importance of phase
Attempts at explaining the importance of phase
Algorithms for reconstructing a signal from its phase
Potential applications

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6 IMPORTANCE OF PHASE IN SIGNALS,

by

10 Alan V. Oppenheim and Jae S. Lim

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Presented at 1980 L'Aquila workshop on
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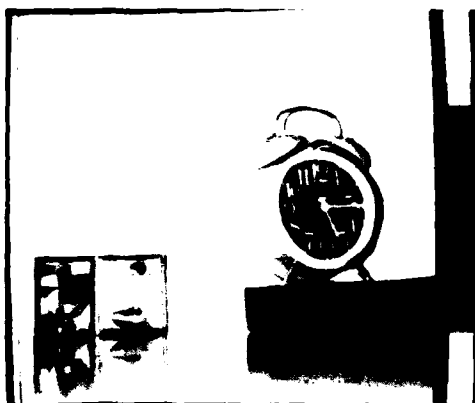
ABSTRACT

- * Experimental results supporting the importance of phase
- * Attempts at explaining the importance of phase
- * Algorithms for reconstructing a signal from its phase
- * Potential applications

This work was supported by the Advanced Research Projects Agency monitored by ONR under Contract N00014-75-C-0951, NR 049-328.

EXPERIMENTAL RESULTS

* Fourier synthesis of images



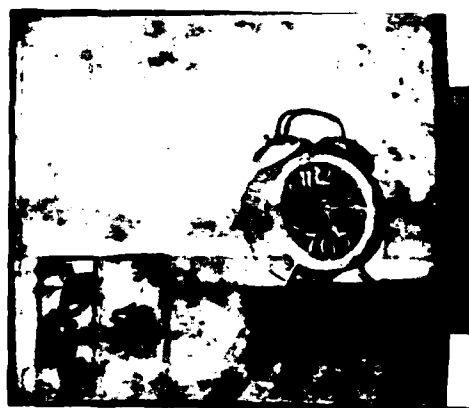
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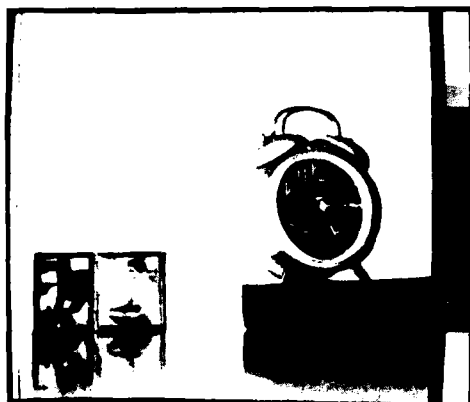
phase: zero
magnitude: exact



phase: exact
magnitude: unity



phase: exact
magnitude: average



original (A)



original (B)

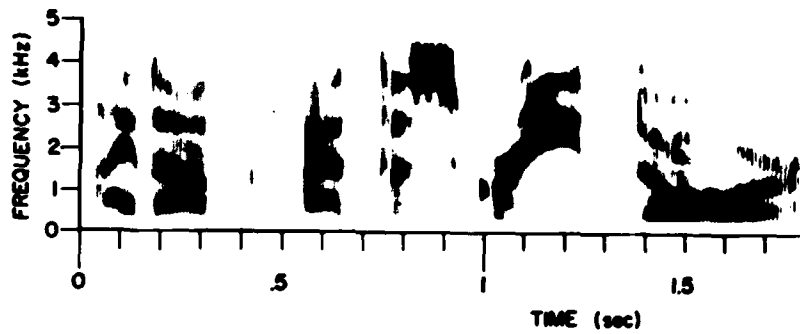


phase: A
magnitude: B

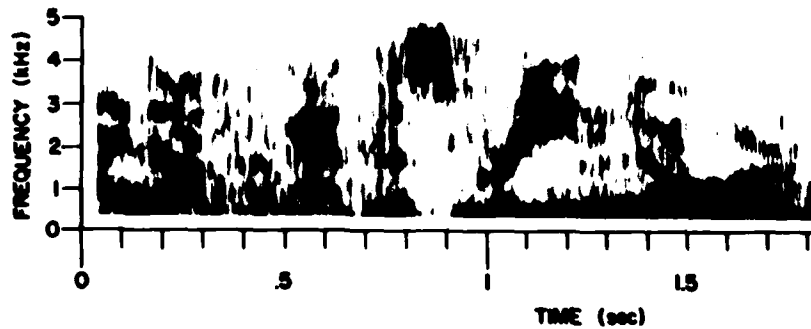


phase: B
magnitude: A

* Fourier synthesis of speech

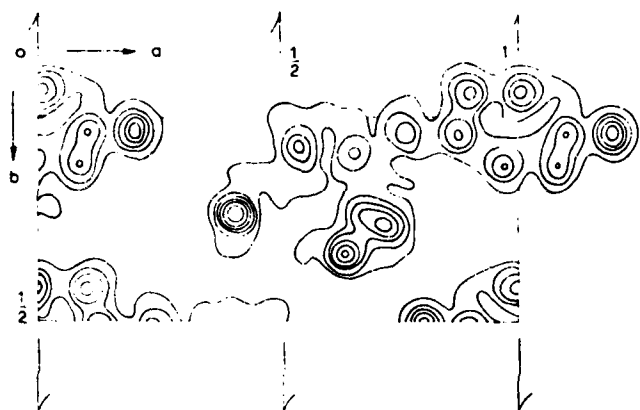


original
(spectrogram of a sentence "Line up at the screen door")

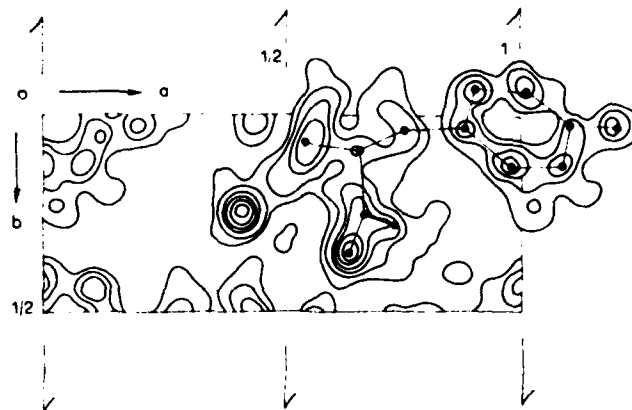


phase: exact
magnitude: unity

* Fourier synthesis of crystallographic structure

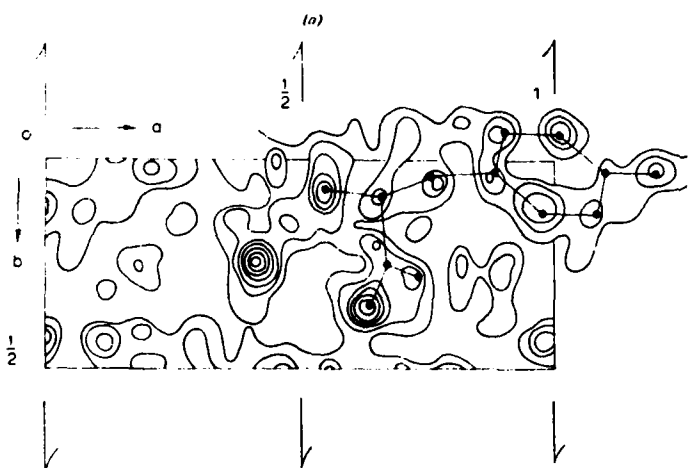


original



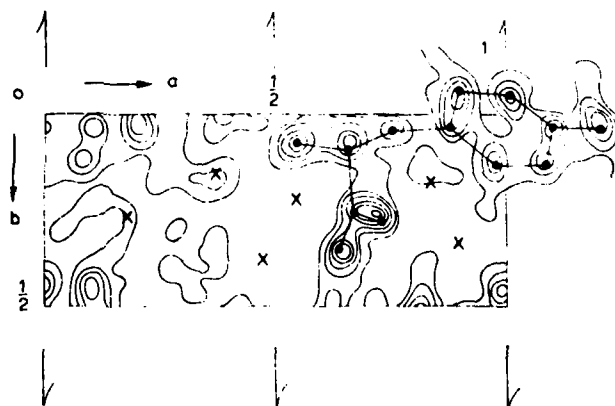
phase: exact

magnitude: tapered constant



phase: exact

magnitude: random permutation
of exact magnitude



phase: exact

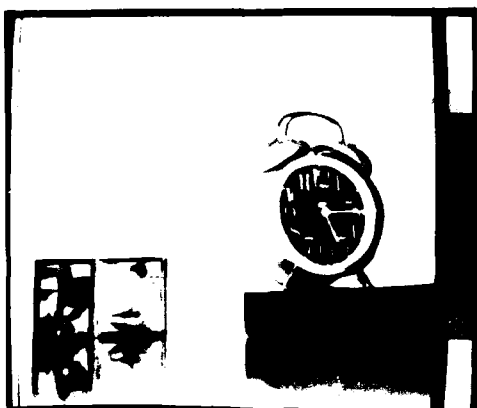
magnitude: a different
structure

ATTEMPTS AT EXPLAINING IMPORTANCE OF PHASE

- * For equal RMS error, phase requires two more bits than magnitude (Tescher)
- * Distortion rate theory--For equivalent distortion, phase requires 1.37 bits more than magnitude (Pearlman and Gray)
- * 78% of kinoform (phase-only hologram) represents original image. 22% higher order terms (Kermisch)
- * Relation of correlation of two structures to the correlation of their magnitude-only and phase-only reconstructions: closer for phase-only than magnitude-only (Srinivasan and Chandrasekaran)
- * Event preservation due to zero-phase filtering or edge enhancement due to high-pass filtering (Oppenheim, et.al.)
- * $x(n)$ uniquely specified by $N-1$ phase samples if
 - (a) $x(n)$ finite duration of length $\leq N$ and
 - (b) $X(z)$ has no conjugate reciprocal zeros.extendable to 2-D sequences (Hayes, Lim, Oppenheim)

ALGORITHMS FOR SIGNAL RECONSTRUCTION FROM PHASE

* Combining exact phase with unity magnitude

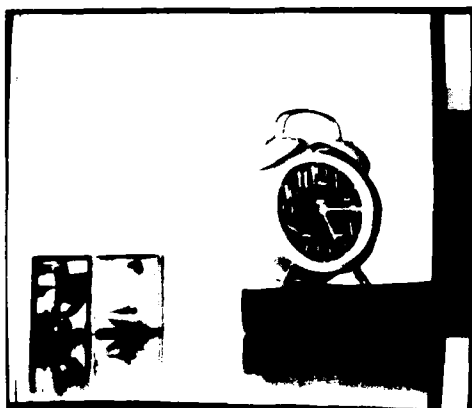


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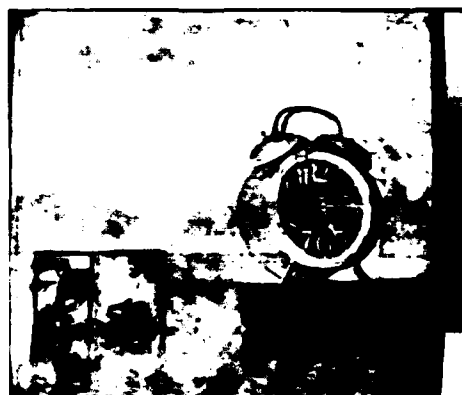


phase: exact
magnitude: unity

* Combining exact phase with average magnitude

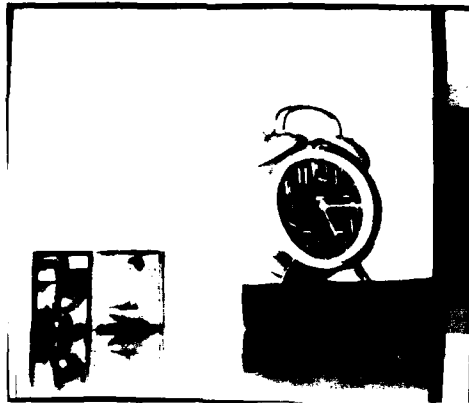


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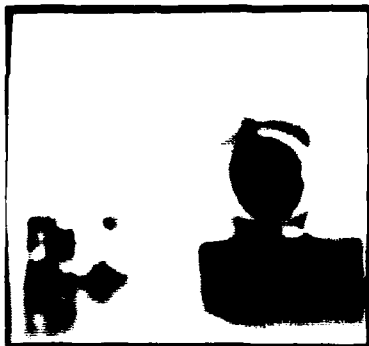


phase: exact
magnitude: average

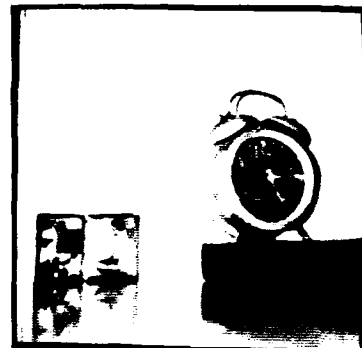
- * Combining exact phase with magnitude estimated from degraded magnitude (assumes degraded magnitude is available)



original



degraded by blurring
with zero-phase blurring function
of short duration

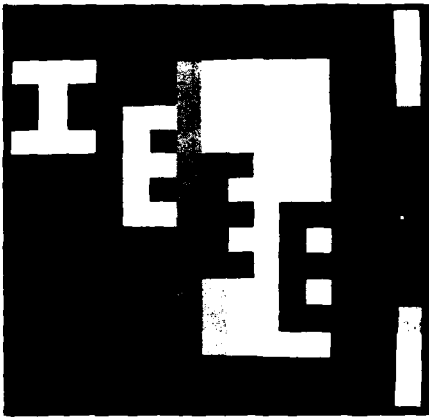


phase: exact
magnitude: estimated

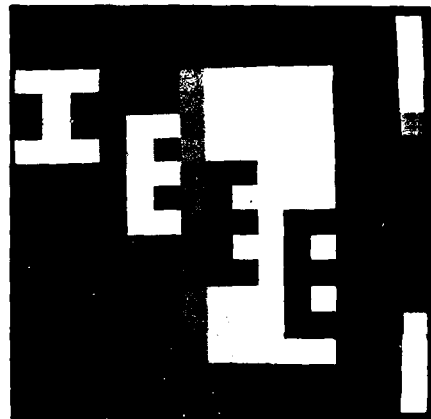
- * Exact reconstruction from phase (assumes the sequence satisfies conditions for unique specification)

A. closed form solution

definition of phase \rightarrow a set of $N-1$ linear equations
for a sequence of length N



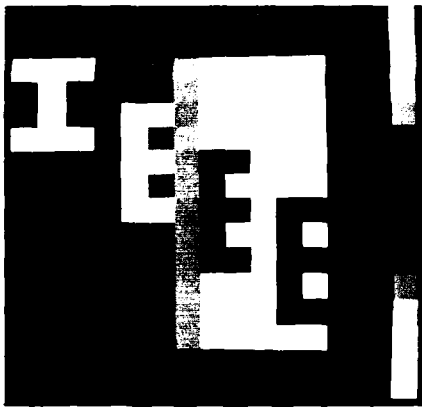
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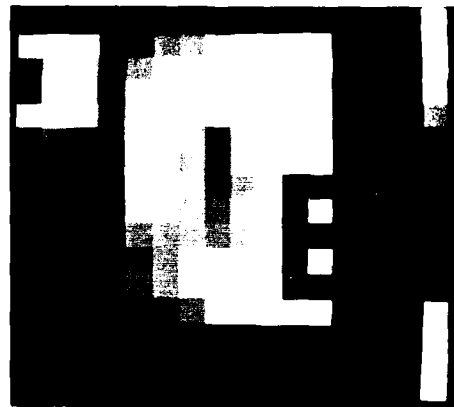
reconstructed

B. Iterative solution

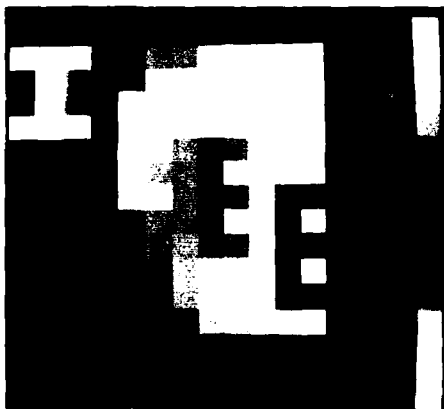
In each iteration, impose known time and frequency domain constraints (sequence is finite in duration and is constrained by known phase samples)



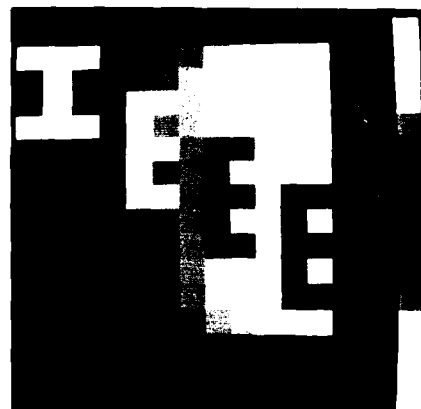
original



result after 10 iterations



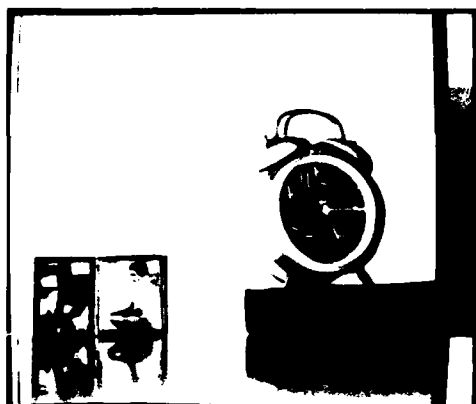
result after 50 iterations



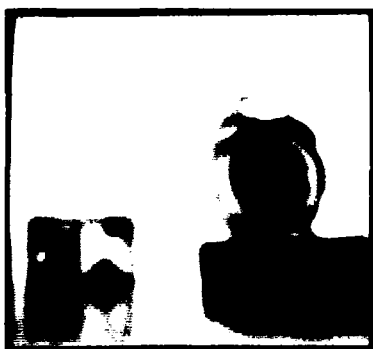
result after 400 iterations

POTENTIAL APPLICATIONS

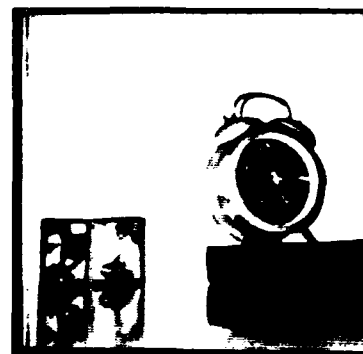
* Blind deconvolution



original



zero phase blurring



restored

- * Fourier transform signal coding

Code only phase and reconstruct the signal from only its phase.

- * Improvement of computer generated holograms

- * Signal registration

- * Signal restoration

Importance of phase emphasizes importance of accurate estimation of phase in signal restoration

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